106-06632/

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August 2001

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Brushing Effects on Conifers and Plant Communities in the Southern Interior of British Columbia: Summary of PROBE Results 1991–2000

PRotocol for Operational Brushing Evaluations

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Introduction

The PROBE (PRotocol for Operational Brushing Evaluations) program evaluates the effects of operational brushing treatments on conifers and plant communities in the southern interior of British Columbia. It was developed in 1990 in the Kamloops Forest Region, and currently includes 96 permanent trials in the Kamloops and Nelson forest regions that have been measured for up to 5 years.

The objectives of PROBE were to study the effects of vegetation management treatments on conifer survival, growth, health, and potential for achieving free-growing, and also on the structure, diversity, and condition of the plant community. Trials were established on adequately stocked sites that were to be operationally brushed, and the treated area was compared with an adjacent untreated control. Sites that were similar in vegetation complex, conifer species, ecosystem, and brushing treatment were grouped together for analysis. PROBE results can be useful in evaluating vegetation management treatment effectiveness, improving treatment regimes, and evaluating and predicting effects on ecosystem components (e.g., wildlife habitat).

In this Extension Note, we report 1- to 5-year results of manual, chemical, and grazing brushing treatments in eight southern interior vegetation complexes. The complexes are: *Fireweed*, *Fern*, *Mixed Shrub*, *Ericaceous Shrub*, *Dry Alder*, *Wet Alder*, *Aspen*, and *Mixed Broadleaf-Shrub*. Full results are available in Land Management Handbook 48 (Simard et al. 2001).

PROBE Methodology

Each PROBE installation consisted of a treatment plot (treated operationally with the rest of the opening) and a control plot (area left untreated in the same opening) that had similar site history and ecosystem characteristics. Each plot was about 0.8 ha in area. Thirty-six crop tree–centred subplots were established on a grid within each of the treatment and control plots.

Within each of the 36 subplots, crop tree size, condition, damage, and degree of overtopping were assessed prior to the brushing

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treatment. For each dominant plant species and vegetation group (total vegetation, herbs, shrubs, and broadleaf trees), modal height, percent cover, and density of broadleaf trees were measured. Average height growth rates for conifers and vegetation were used to predict the time needed to reach the conifer:vegetation height requirement of free-growing. In four of the subplots, the percent cover, distribution, and vigour of all vascular plant species were recorded, and species and structural richness and diversity (Shannon-Weaver and Simpson indices) were calculated. These measurements are being repeated 1, 3, 5, and 10 years after treatment.

Statistical analysis was carried out when each combination of vegetation complex/conifer species/ecosystem/brushing treatment had been replicated at least three times. Analysis of variance (ANOVA) was conducted separately for each measurement year for quantitative crop tree and vegetation variables, and summary statistics were produced for qualitative variables. Regression analysis was used to examine individual tree responses to neighbourhood vegetation abundance and the importance and intensity of competition were evaluated on the basis of adjusted r^2 and slope, respectively, after Weldon and Slanson (1986). Scattergrams were used to identify complex and conifer species-specific competition thresholds, which were competition levels above which conifer diameter declined sharply in response to increasing vegetation abundance. Competition indices used to define thresholds were (a) cover of individual species or species groups (e.g., "fireweed cover" for the *Fireweed* Complex and "shrub cover" for the *Mixed Shrub* Complex), (b) CRH, where CRH = (species or species group cover * modal height)/conifer height, and (c) density of broadleaf trees (stems/ha). Further details on PROBE methodology are provided in Simard (1993) and Simard et al. (2001).

FIREWEED Complex

The *Fireweed* Complex consists of almost pure fireweed on newly disturbed sites, but as time passes following disturbance, it may include minor components of grasses, ferns, and various shrubs (Figure 1). This community is widespread across British Columbia, wherever moisture is sufficient. In southern interior British Columbia, it occurs most abundantly on mesic and subhygric sites in the ICH, ESSF, and MS zones, and to a lesser extent in the IDF. It is encouraged by treatments that increase light (e.g., harvesting) and by those that disturb the forest floor, particularly if mineral soil is exposed (e.g., summer- rather than winter-logged sites). The *Fireweed* Complex is thought to reduce light availability to understorey conifers, and may cause physical damage through snow- and vegetation-press. On high-elevation sites, it may also inhibit soil and air warming in the seedling micro-environment. The complex may benefit conifer seedlings through turnover of its foliage and nutrients, by slowing the development of more competitive shrub communities, and by reducing insect damage to seedling leaders.

FIGURE 1 *The Fireweed Complex prior to brushing in the ESSFwc1 variant.*
Photo credit: JMJ Holdings Inc.

Four brushing treatments were examined for the *Fireweed* Complex:

- Manual cutting in 2- to 4-year-old Engelmann spruce plantations in the ESSF/ICH zones. Vegetation was cut in 0.5–1.0 m radii around seedlings on dates in July to October. Three sites received single-pass treatments, and one received two passes. We report 3-year results.
- Manual cutting in 1- to 3-year-old lodgepole pine plantations in the ICH/ESSF zones. Vegetation was cut in 1.0 m radii around seedlings on two sites, and was broadcast cut on a third site. Treatments were applied in July. We report 5-year results.
- Foliar glyphosate application in 1- to 5-year-old Engelmann spruce

plantations in the ESSF/ICH zones. Application rates were 1.4–2.1 kg ai/ha, by backpack sprayer on two sites and aerially on a third site. We report 5-year results.

- Grazing in 0- (newly planted) to 5-year-old Engelmann spruce plantations in the ESSF. Single-pass grazing took place between June and August. Sheep were used on two sites, and cattle on a third site. We report 1-year results.

Seedling survival responses (Table 1)

- None of the brushing treatments (manual, foliar glyphosate, or grazing) had a significant effect on seedling survival. Average overall survival ranged from 88% to 96%.
- Vegetation competition was the most common cause of mortality, but wildlife damage and root disease also killed some seedlings. Cattle trampled many seedlings on one site, but sheep caused no damage.

Seedling growth responses (Table 1)

- There were no significant improvements in diameter, height, leader length, or height:diameter (H:D) ratio for spruce as a result of manual cutting or grazing, or for pine as a result of manual cutting.
- Foliar glyphosate application significantly reduced spruce H:D ratio for at least 5 years. It resulted in a temporary increase in diameter (data not shown), but the effect had disappeared by year 5.
- Neither manual cutting nor grazing are expected to reduce the time it will take for spruce to outgrow the fireweed canopy (Figure 2). However, manual cutting allowed lodgepole pine to surpass the canopy approximately 1 year sooner, on average, than control seedlings (Figure 3). We predict that the glyphosate treatment will allow spruce to outgrow the fireweed canopy approximately 3 years sooner than in the control (Figure 4).

Vegetation responses (Tables 2 and 3)

- Single manual cutting treatments did not reduce cover or height of fireweed, the herb layer, the shrub layer, or total vegetation for more than a single season.
- Single grazing treatments reduced herb height for 1 year, but did not affect any other component of the vegetation.
- Foliar glyphosate significantly reduced cover and height of fireweed, herbs, and shrubs for at least 5 years. Total vegetation cover was also reduced for at least 5 years following treatment, but total height recovered after 1 year.
- None of the brushing treatments we studied (manual cutting, foliar glyphosate, or grazing) affected the richness or diversity of vascular plant species associated with the *Fireweed* Complex.

Competition thresholds (Table 4)

- Competition was of low importance and intensity in the *Fireweed* Complex, which helps explain why pine naturally outgrew the vegetation and why spruce is also predicted to do so.
- Competition thresholds for conifer diameter were 35, 46, and 40% fireweed cover, and 46, 60, and 49 CRH for spruce in the ESSF zone, spruce in the ICH zone, and pine in the ICH zone, respectively.
- The threshold values suggest that spruce tolerates slightly higher levels of fireweed in the ICH than in the ESSF, possibly because of the milder climate.
- The threshold values also suggest that spruce tolerates slightly higher levels of fireweed than does pine in the ICH zone, possibly because of greater shade tolerance.
- These competition thresholds, and other competition and light studies (Delong 1991; Coates and Burton 1999), predict that growth rates for spruce and pine will not be substantially reduced by moderate levels of fireweed.

Management implications

- We found that brushing of the *Fireweed* Complex was not required on mesic sites in the ESSF and ICH zones to ensure good (≥88%) survival of spruce or lodgepole pine seedlings. Manual, chemical, or grazing treatments did not substantially improve seedling growth. This is probably because seedlings were experiencing low competitive stress on these sites.
- Our results suggest that spruce and pine seedlings will reach free-growing on mesic sites in the ICH and ESSF zones 6–9 years after planting, regardless of whether or not the *Fireweed* Complex is brushed.
- Further study is required to identify sites where competition from this community is intense enough to threaten seedling performance. Other studies suggest that competition is more severe and that brushing is required to improve survival and growth on wetter sites. On those sites, either broadcast glyphosate or three repeat manual cutting treatments, best applied in summer, may be necessary to improve spruce growth (Comeau et al. 2000).
- Most seedlings in our study were growing in fireweed neighbourhoods that were below the competition thresholds, regardless of whether they occurred in the treatment or control. Seedlings growing in neighbourhoods

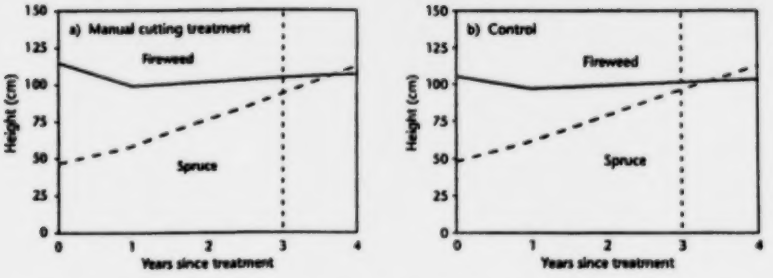

FIGURE 2 *Comparison of average spruce and fireweed height profiles in (a) the manual cutting treatment and (b) the control in the ESSF/ICH* Fireweed *Complex. The vertical dashed line indicates the most recent assessment year, and subsequent heights are based on growth rates determined from the latest measurement year.*

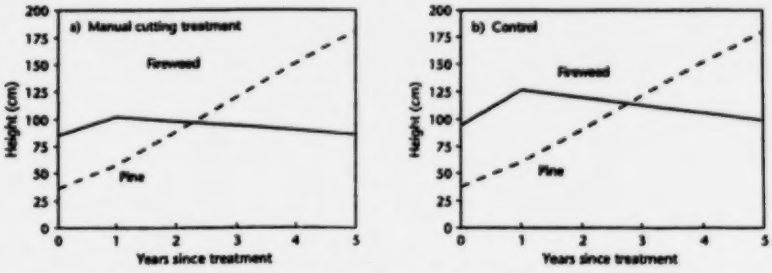

FIGURE 3 *Comparison of average lodgepole pine and fireweed height profiles in (a) the manual cutting treatment and (b) the control in the ICH/ESSF* Fireweed *Complex during the 5-year measurement period.*

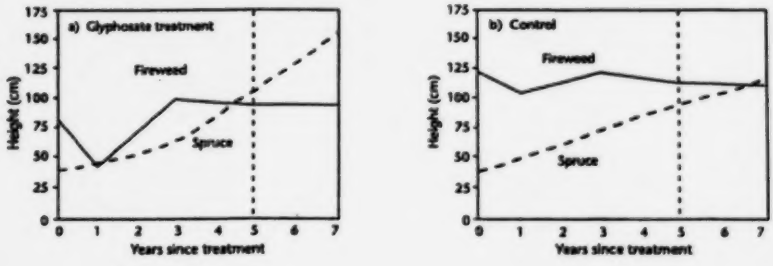

FIGURE 4 *Comparison of average spruce and fireweed height profiles in (a) the foliar glyphosate treatment and (b) the control in the ESSF/ICH* Fireweed *Complex. The vertical dashed line indicates the most recent assessment year, and subsequent heights are based on growth rates determined from the latest measurement year.*

above the thresholds will likely benefit from selective brushing.

- None of the brushing treatments we studied (manual cutting, foliar glyphosate, or grazing) affected the richness or diversity of vascular plant species associated with the *Fireweed* Complex. However, foliar glyphosate tended to reduce the cover of berry-producing shrubs. Other studies suggest that repeated sheep grazing has the potential to cause species shifts because of sheep preferences for certain forage species, and because of the potential for introduction of exotic species (Newsome et al. 1995).

FERN COMPLEX

The *Fern* Complex is characterized by the presence of lady fern, bracken, and lesser amounts of spiny wood fern. Thimbleberry, red raspberry, fireweed, devil's club, and elderberry are also common (Figure 5). The *Fern* Complex occurs mainly on medium to wet sites in the ICH zone where ferns were present in the understorey prior to logging. It is encouraged by light to moderate burns and discouraged by mechanical site preparation. The complex appears to reduce light availability to understorey conifers, and may physically damage young seedlings when the dense foliage is shed in the fall. Conversely, the vegetation canopy may also protect seedlings against summer frost. The annual turnover of foliage may also improve nutrient availability to seedlings.

One brushing treatment was examined in the *Fern* Complex:

- Foliar glyphosate application in 2- to 4-year-old hybrid spruce plantations in the ICH zone. Glyphosate was applied in August at rates of 1.24–1.78 kg ai/ha. Application was by helicopter on

two sites and backpack sprayer on a third site. We report 5-year results.

Seedling survival responses (Table 1)

- Brushing was not needed to ensure good (93%) survival of 2- to 4-year-old spruce. However, silviculture survey data suggest that considerable mortality occurred between the time of planting and brushing.
- Vegetation competition and vegetation press were the main causes of mortality in the post-treatment assessments.
- Seedling vigour declined in both the treatment and the control because of vegetation competition.

Seedling growth responses (Table 1)

- Spruce growth improved within 3 years of glyphosate application. By year 5, spruce seedlings in the treatment had larger diameters, were taller, had longer leaders, and had lower H:D ratios than those in the control.
- Seedlings in the glyphosate treatment were taller than the vegetation within 1 year of brushing, but those in the control also outgrew the vegetation by year 5 (Figure 6).

Vegetation responses (Tables 2 and 3)

- Foliar glyphosate reduced cover and height of lady fern, thimbleberry, and total vegetation within 1 year of treatment. Treatment effects were still significant after 5 years.
- Cover and height of the shrub and herb layers were also reduced for at least 5 years (data not shown).
- Brushing with glyphosate did not affect the richness or diversity of vascular plant species. However, it tended to reduce abundance of two berry-producing shrubs, black huckleberry and thimbleberry.

Competition thresholds (Table 4)

- Competition was of moderate importance and intensity in the *Fern* Complex, which helps explain why conifer growth increased following brushing.
- A threshold was not evident when herb cover was used as the competition index, and was 58 when CRH was used. The ability to identify CRH but not cover thresholds indicates that conifer diameter growth was affected by herb height, possibly because it reduced light availability, but that it varied similarly across a wide range in cover values.
- Half of the spruce trees were growing in dense, tall herb patches above the CRH threshold. Chemical brushing reduced vegetation abundance to below the CRH threshold for about three-quarters of treated seedlings.
- The foliar glyphosate treatment improved both mean spruce diameter growth and the distribution of spruce diameters across

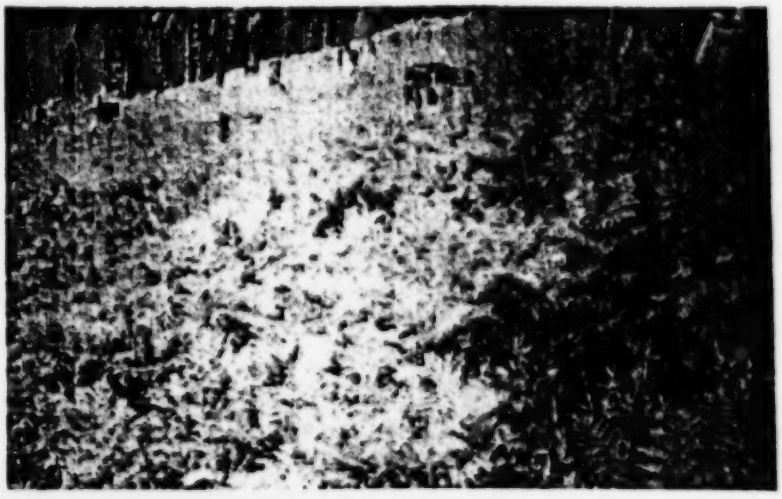

FIGURE 5 *The Fern Complex prior to brushing in the ICHwk1 variant.*
Photo credit: Silver Ring Forestry Ltd.

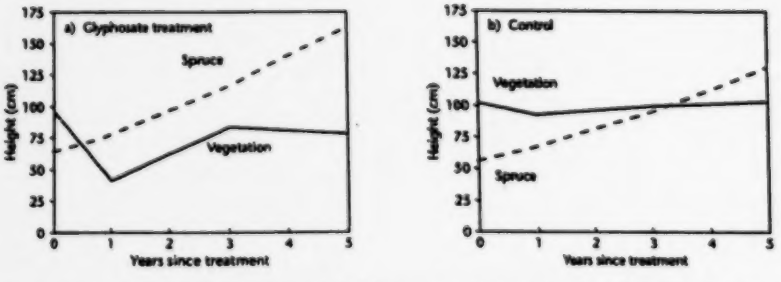

FIGURE 6 *Comparison of average hybrid spruce and vegetation height profiles in (a) the foliar glyphosate treatment and (b) the control in the ICH Fern Complex during the 5-year measurement period.*

herb neighbourhoods. This indicates that the reductions in herb abundance improved growing conditions for the conifers.
- Brushing treatments that reduce herb abundance and stature below the identified CRH threshold should improve diameter growth of spruce seedlings.

Management implications
- In our study, 2- to 4-year-old spruce growing among a vigorous *Fern* Complex did not require brushing to maintain good (93%) survival. However, earlier brushing is likely to have offset the mortality and loss of vigour that apparently occurred prior to brushing. Early brushing of the *Fern* Complex has become standard practice on lady fern and devil's club site series in the southern interior (J. Wright, pers. comm., 2001).
- Our results show that brushing the *Fern* Complex with glyphosate improved spruce growth and resulted in stockier seedlings that were likely more resistant to damage from snow- and vegetation-press.
- Brushing with glyphosate had no effect on species richness or diversity. However, it tended to reduce the abundance of some berry-producing shrubs.
- Brushing the *Fern* Complex was not required for seedlings in our study to meet the minimum height and conifer:vegetation height ratio requirements for free-growing 6–8 years after planting.

MIXED SHRUB COMPLEX

The *Mixed Shrub* Complex is typically a lush mixture of shrubs and herbs (Figure 7). Many of the species are the same as those found in the *Fireweed* and *Fern* complexes, but as long as shrubs dominate the community, it is classified as *Mixed Shrub*. In southern interior British Columbia, the *Mixed Shrub* Complex is common on medium to wet sites in the ICH zone, including those that are transitional to the ESSF. It is often found on sites where conifer growth is highly productive. The complex appears to inhibit conifer performance by reducing light availability to understorey conifers and by encouraging snow- and vegetation-press. It may benefit seedlings by reducing summer frost damage and by improving nutrient availability through annual litter turnover. Manual cutting, foliar glyphosate application, and grazing are the most common brushing treatments applied to this complex.

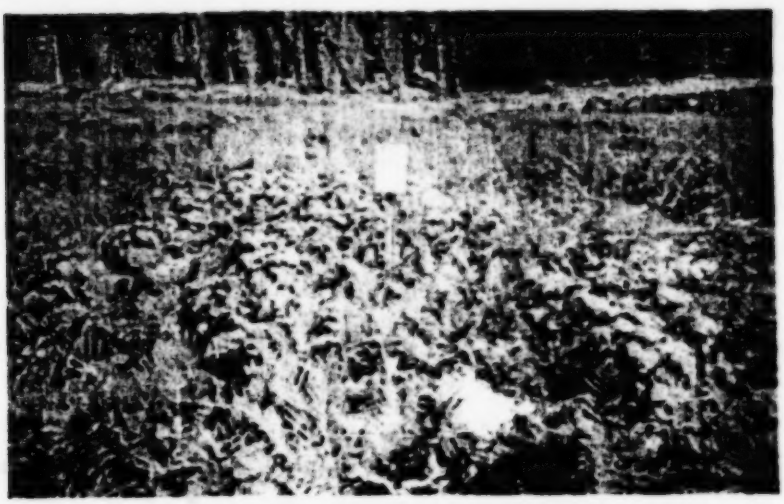

FIGURE 7 *The* Mixed Shrub *Complex prior to brushing in the ESSFwc1 variant.*
Photo credit: JMJ Holdings Inc.

Two brushing treatments were examined in the *Mixed Shrub* Complex:
- Manual cutting in 0- (newly planted) to 2-year-old hybrid spruce plantations in the ICH/ESSF zones. Vegetation was cut in 0.75–1.5 m radii around seedlings on dates in July to August. All three sites received single-pass treatments. We report 3-year results.
- Grazing in 1- to 2-year-old hybrid spruce plantations in the ICH/ESSF zones. Single-pass sheep grazing took place between June and August. We report 1-year results.

Seedling survival responses (Table 1)
- Neither manual cutting nor sheep grazing improved survival of spruce seedlings growing in the *Mixed Shrub* Complex.
- Three years after manual cutting, survival was moderate in both the treatment and the control (average 75%). One year after grazing, survival was good (average 94%), but declining vigour in both the treatment and control suggests that further mortality will occur.
- Most seedling mortality in the *Mixed Shrub* Complex was caused by vegetation competition.

Seedling growth responses (Table 1)
- Within 3 years of manual cutting,

spruce diameter increased in the treatment compared with the control, and H:D ratio was reduced. Seedling height was unaffected by the treatment.
- One year after grazing there were no seedling growth responses.
- Spruce in the manual cutting treatment are predicted to outgrow the vegetation canopy after about 5 years, and those in the control after about 6 years (Figure 8).

Vegetation responses (Tables 2 and 3)
- A single manual cutting treatment significantly reduced total vegetation height and shrub cover for 1 year, but the actual reductions were small.
- A single grazing treatment reduced fireweed cover and height for at least 1 year, but no other vegetation components were affected.
- Diversity of vascular plant species decreased 3 years after the *Mixed Shrub* Complex was manually cut. This was due to a decrease in the abundance of common shrubs (thimbleberry, elderberry, black huckleberry) and herbs (spiny wood fern, oak fern, small twisted-stalk, dandelion, grasses) following cutting. Species richness was unaffected by cutting. Grazing had no effect on either species richness or diversity.

Competition thresholds (Table 4)
- Competition was of moderate importance and low intensity in the *Mixed Shrub* Complex, which helps explain the small increase in conifer growth following brushing.
- The competition threshold averaged 74% shrub cover, and did not vary among the three tree species. The threshold was high because spruce diameter varied widely across a broad range of shrub cover classes. Only about 12% of trees were growing in neighbourhoods above the threshold, and brushing reduced most trees to well below threshold values.
- The CRH thresholds were 48 for Douglas-fir, 84 for hybrid spruce, and 187 for western redcedar. Ranking of thresholds among tree species followed species patterns of shade tolerance.

Management implications
- Our results indicated that neither single manual brushing nor single grazing treatments sufficiently reduced vegetation abundance in the *Mixed Shrub* Complex to improve spruce survival on mesic ICH/ESSF sites. Three years after manual cutting, survival was moderate (average 75%).
- Other studies suggest that seedling survival may be at risk due to vegetation competition on *Mixed Shrub* sites that are wetter than mesic (Comeau et al. 2000). In that case, two or three manual cuttings or grazing seasons, or a single glyphosate treatment, appear necessary to reduce vegetation competition sufficiently to improve seedling performance.
- Seedling diameter increased slightly and H:D ratio decreased as a result of manual cutting in our study, which agrees with the minor and short-lived reductions in vegetation abundance.
- Competition threshold results suggest that shrub cover alone was a poor measure of competition from the *Mixed Shrub* Complex, and that seedlings can be expected to respond variably to brushing.
- Our results suggest that brushing the *Mixed Shrub* Complex will not be necessary for seedlings to meet free-growing requirements on mesic ICH/ESSF sites 6–8 years after planting. Brushing may be required, however, on wetter *Mixed Shrub* sites, where vegetation competition can threaten seedling survival.

ERICACEOUS SHRUB COMPLEX

The *Ericaceous Shrub* Complex is most often dominated by white-flowered rhododendron, and can also include false azalea, black huckleberry, and oval-leaved blueberry (Figure 9). The complex occurs predominantly in wet ESSF and upper ICH subzones, on dry to moist sites. This plant community develops relatively slowly following logging, but may become dominant on sites where ericaceous shrubs were

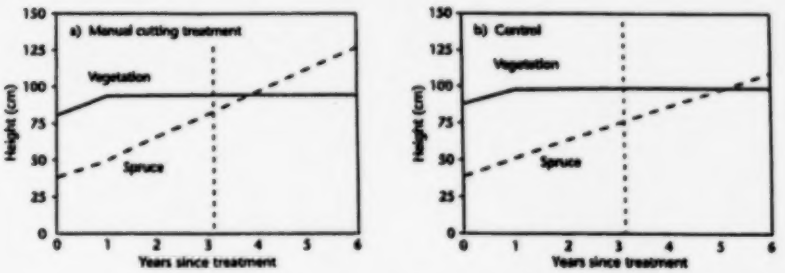

FIGURE 8 *Comparison of average spruce and vegetation height profiles in (a) the manual cutting treatment and (b) the control in the ICH/ESSF* Mixed Shrub *Complex. The vertical dashed line indicates the most recent assessment year, and subsequent heights are based on growth rates determined from the latest measurement year.*

common in the understorey prior to harvest. It is especially likely to develop on winter-logged sites where snow has protected pre-harvest vegetation. The complex appears to negatively affect conifer performance by reducing light availability to understorey conifers, encouraging damage from snow- and vegetation-press, and restricting soil and air warming. However, the complex may also reduce summer frost damage to conifers and restrict development of the *Subalpine Herb* Complex, which may be more competitive with conifers. The most common brushing treatments applied to this community are manual cutting and foliar glyphosate.

One brushing treatment was examined in the *Ericaceous Shrub* Complex:

- Manual cutting in 0- (newly planted) to 2-year-old Engelmann spruce plantations in the ESSF zone. Vegetation was cut in 0.5–2.0 m radii around seedlings on dates in July to mid-September. Two sites received single-pass treatments, and two received two passes. We report 5-year results.

Seedling survival responses (Table 1)

- Manual cutting significantly improved spruce survival in the *Ericaceous Shrub* Complex. After 5 years, survival was 89% in the treatment compared with 71% in the control.
- Vegetation competition was responsible for three-quarters of the mortality in the control and for half of the mortality in the treatment. Poor planting, wildlife, and *Armillaria* root disease accounted for the rest.

Seedling growth responses (Table 1)

- Minor improvements in spruce seedling growth occurred as a result of manual cutting. After 5 years, spruce leaders were longer in the treatment than in the control and H:D ratios were lower. Seedlings in both the treatment and control were growing at below-average rates.
- Manual cutting is predicted to reduce the amount of time required for spruce to outgrow the vegetation canopy by about 4 years (Figure 10).

Vegetation responses (Tables 2 and 3)

- Ericaceous shrubs recovered slowly following the tree-centred manual cutting treatments. The cover and height of total vegetation and shrubs were reduced for 1 year, after which the differences were no longer significant. The reductions appeared small and short-lived because vegetation was measured in a larger radius than in the cutting treatment, and therefore included both cut and uncut plants. Cover and height of the herb layer did not increase as a result of cutting.
- Manual cutting increased the diversity of vascular plant species for 3 years, but, by year 5, there were no differences between the treatment and control. The difference reflects a minor and short-lived reduction in the dominance of shrub species. Species richness was not affected.

Competition thresholds (Table 4)

- Competition was of moderate importance and low intensity in the *Ericaceous Shrub* Complex, which helps explain the small increase in conifer growth following brushing.
- Competition thresholds were 52% shrub cover and 73 CRH. Brushing treatments should aim to reduce local shrub abundance below the identified thresholds.
- Without cutting, 60% of control spruce were growing in neighbourhoods above the competition thresholds. After cutting, 75% of treated trees were in neighbourhoods below the thresholds, indicating that manual cutting was moderately successful at improving seedling competitive environments.

FIGURE 9 *The Ericaceous Shrub Complex prior to brushing in the ESSFdk subzone.*
Photo credit: JMJ Holdings Inc.

Management implications

- Manual cutting of the *Ericaceous Shrub* Complex improved survival of Engelmann spruce that were 0 (newly planted) to 2 years old at the time of cutting. Our results suggest that stocking requirements may not be met without brushing on sites where this complex is well-developed.
- Growth of spruce seedlings improved marginally following brushing, which is consistent with the small reductions in vegetation following manual cutting. Other studies of the *Ericaceous Shrub* Complex have shown that seedling growth responses are positively correlated with the degree of vegetation and forest floor removal, and with resultant increases in soil temperature (Coates et al. 1991).
- Our competition threshold results suggest that reducing abundance of the *Ericaceous Shrub* Complex to below 52% shrub cover and 73 CRH on a localized basis may improve spruce diameter growth.
- Herbs did not increase in our study because shrubs were selectively cut in small tree-centred radii. However, caution should be used when brushing the *Ericaceous Shrub* Complex because the herb layer may increase, potentially creating a more competitive environment for seedlings.
- Manual cutting is unlikely to have a lasting effect on richness or diversity of vascular plant species.
- Manual cutting appears to have helped meet the conifer:vegetation height ratio requirement for free-growing, and it may also improve stocking of preferred species.
- Manual cutting reduced the predicted time taken for spruce to meet minimum height and conifer:vegetation height ratio requirements by 2–3 years compared with no treatment.

DRY ALDER COMPLEX

The *Dry Alder* Complex is dominated by Sitka alder, and willow is also present on some sites (Figure 11). Common understorey species are fireweed on mesic and wetter sites, and pinegrass on drier sites. Thimbleberry is also commonly present. The *Dry Alder* Complex is most common in the MS zone, but it is also found in the ICH, SBS, upper IDF, and lower ESSF zones. This community is encouraged by ground disturbance during logging, mechanical site preparation, and burning treatments that create suitable seedbeds for alder or that stimulate existing root crowns to sprout. Severe fires or mechanical disturbances that destroy root systems hinder development of this complex. Potential negative effects on conifer seedlings are reduced light availability on mesic sites and reduced water availability on drier sites. Soil and air warming may also be slightly inhibited by alder. Potential benefits include improved nitrogen availability and reduced summer frost damage. The complex is most commonly brushed by manual cutting or foliar glyphosate application.

One brushing treatment was examined in the *Dry Alder* Complex:

- Manual cutting in 5- to 7-year-old lodgepole pine plantations in the MS zone. Alder was broadcast cut on two sites and patches were left on a third site. The single-pass treatments were applied between mid-August and mid-September. We report 5-year results.

Seedling survival responses (Table 1)

- Brushing did not improve pine survival, which was excellent in both the treatment and the control (average 98% in year 5).

Seedling growth responses (Table 1)

- Five years after cutting, there were no improvements in lodgepole pine diameter, height, leader length, or H:D ratio as a result of manual cutting. Pine were growing at adequate rates (Vyse and Navratil 1985) in both the treatment and the control.
- Brushing immediately reduced alder height below that of pine; however, control pine naturally outgrew the alder canopy within 3 years (Figure 12).

Vegetation responses (Tables 2 and 3)

- Manual cutting significantly reduced height of alder in year 1,

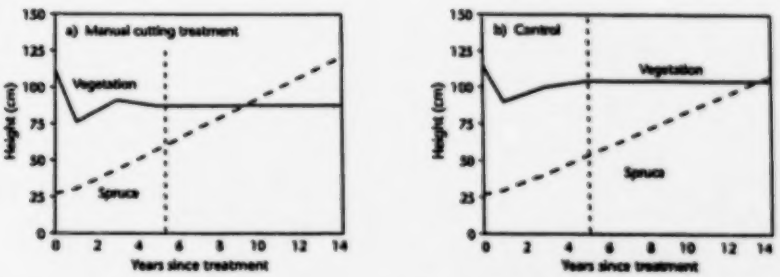

FIGURE 10 *Comparison of average spruce and vegetation height profiles in (a) the manual cutting treatment and (b) the control in the ESSF* Ericaceous Shrub *Complex. The vertical dashed line indicates the most recent assessment year, and subsequent heights are based on growth rates determined from the latest measurement year.*

and it had recovered to only 65% of control height by year 5. Differences in alder height were not significant after year 1 because of variability between sites. Alder cover was not significantly affected by cutting.
- Ninety percent of alder stumps sprouted in the first year after cutting. By year 5, 54% of stumps still had an average of four sprouts each, and the average height was 104 cm (data not shown).
- Cutting had no effect on herb abundance.
- Manual cutting had no effect on species richness or diversity in the *Dry Alder* Complex.

FIGURE 11 *The Dry Alder Complex prior to brushing in the MSdc subzone.*
Photocredit: Jean Mather.

Competition thresholds (Table 4)
- Competition was of low importance and intensity in the *Dry Alder* Complex, which helps explain why pine naturally outgrew the vegetation.
- Competition thresholds were 33% alder cover, which agrees with Simard (1990), and 38 CRH. Brushing treatments should aim to reduce localized alder abundance below the identified thresholds.
- Most pine in the control were growing in neighbourhoods below the thresholds, suggesting that most trees naturally were not constrained by alder competition.

Management implications
- Manual cutting of the *Dry Alder* Complex was not required to improve survival (average 97% in the treatment and the control) or growth of lodgepole pine that had been outplanted for 5–7 years at the time of brushing.
- Most pine in both the treatment and the control were growing in neighbourhoods below the identified competition thresholds. Alder in the *Dry Alder* Complex typically had a clumped distribution, with conifers growing mainly between the clumps. It is likely that only those pine growing within alder clumps experienced growth-inhibiting competition.
- Manual cutting reduced alder abundance, but rates of recovery were variable. Further study is required to identify factors that affect rates of sprout growth.
- Manual cutting of alder did not affect species richness or diversity in the *Dry Alder* Complex.
- Lodgepole pine growing among less than 33% alder cover can be expected to meet free-growing requirements without brushing 8–10 years after planting. Brushing 5–7 years after planting is likely to reduce the time required to meet free-growing by only 1 year.

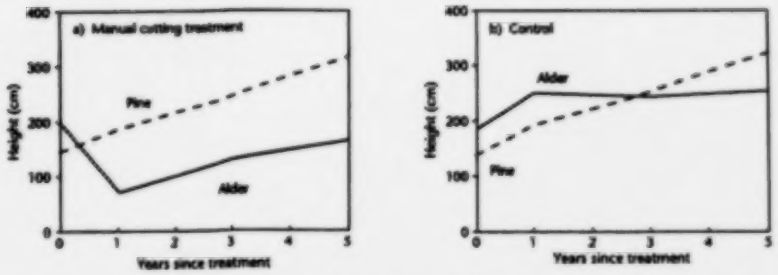

FIGURE 12 *Comparison of average lodgepole pine and alder height profiles in (a) the manual cutting treatment and (b) the control in the MS Dry Alder Complex during the 5-year measurement period.*

WET ALDER COMPLEX

The *Wet Alder* Complex is dominated by Sitka alder and often includes mountain alder (Figure 13). Common understorey species are thimbleberry, black twinberry, lady fern, bluejoint, spiny wood fern, bracken, and fireweed. The *Wet Alder* Complex occurs mainly on rich, wet sites in the ESSF and ICH zones. It is common in seepage areas. This community can develop quickly following both winter and summer logging, but is deterred by site preparation treatments that severely damage alder root systems. The complex appears to reduce light availability to understorey conifers, restrict soil and air warming, and encourage physical damage to seedlings from snow- and vegetation-press. It is most commonly brushed using manual cutting or foliar glyphosate application.

One brushing treatment was examined in the *Wet Alder* Complex:

- Manual cutting in 4- to 6-year-old Engelmann spruce plantations in the ESSF zone. Alder was cut once in variable radii around seedlings between June and August. We report 3-year results.

Seedling survival responses (Table 1)

- Brushing did not improve spruce survival, which was good in both the treatment and the control (average 93%) after 3 years. However, silviculture survey data suggest that considerable mortality had occurred prior to brushing, and survival may have been improved if brushing had been applied earlier.
- Mortality since treatment was due mainly to cutting damage in the treatment and to vegetation competition in the control.

Seedling growth responses (Table 1)

- There were no improvements in spruce diameter, height, or leader length as a result of manual cutting. However, H:D ratio was significantly lower in the cutting treatment than in the control after 3 years.
- Cutting the *Wet Alder* Complex immediately reduced alder height to slightly below that of spruce. Within 2 years, average alder height again exceeded that of seedlings (Figure 14).

Vegetation responses (Tables 2 and 3)

- Manual cutting significantly reduced cover and height of alder for at least 3 years.
- Herb abundance did not increase in response to reductions in tall shrubs.
- Seventy-two percent of alder stumps sprouted following cutting. In year 3, 58% of stumps still had an average of four sprouts each. Sprouts averaged 73 cm tall after 3 years (data not shown).
- Manual cutting reduced species richness in year 1, but the difference was no longer significant by year 3.

Competition thresholds (Table 4)

- Competition was of low importance and moderate intensity in the *Wet Alder* Complex, indicating that competition was locally intense, but not very important to overall conifer performance relative to other limiting factors.
- Thresholds were 37% alder cover and 107 CRH. Brushing treatments should aim to reduce localized alder abundance below the identified thresholds.
- About one-third of spruce were growing in neighbourhoods above the competition thresholds. Cutting successfully reduced vegetation abundance to below threshold values for 93% of treated seedlings. Nevertheless, diameter distributions were not improved as a result of cutting, probably because growth-limiting factors were not improved.

Management implications

- Brushing the *Wet Alder* Complex did not affect survival of 4- to 6-year-old Engelmann spruce seedlings. Brushing when seedlings

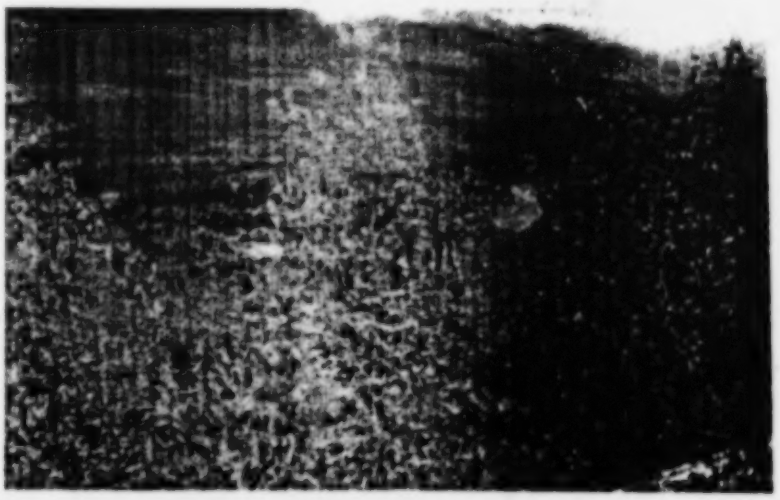

FIGURE 13 *The Wet Alder Complex prior to brushing in the ICHmk1 variant.*
Photo credit: JM Holdings Inc.

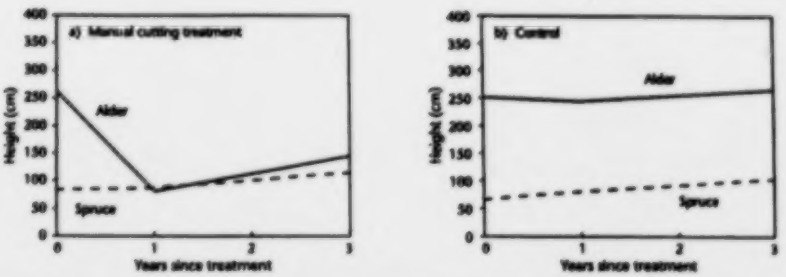

FIGURE 14 *Comparison of average Engelmann spruce and alder height profiles in (a) the manual cutting treatment and (b) the control in the ESSF Wet Alder Complex during the 3-year measurement period.*

were younger, however, may have improved their survival.

- Seedlings on one of our sites were damaged considerably during manual cutting. Cutting must be done with particular care in this complex, especially where there is a dense herb layer that limits seedling visibility.
- Seedling diameter and height growth did not improve within 3 years of manual cutting in the *Wet Alder* Complex. This may be because seedlings were too suppressed at age 4–6 years to respond to release, or because factors other than vegetation competition (e.g., cold, wet soil) were limiting growth.
- Alder did not recover quickly in our study. This differs from other brushing studies, where alder sprouted vigorously (Stathers et al. 1994). Further study is required to identify factors that affect rates of alder sprouting.
- Manual cutting briefly reduced alder height below that of spruce, but seedlings were overtaken within 3 years of cutting. Another brushing treatment will be required for seedlings to meet the conifer:vegetation height ratio for free-growing.

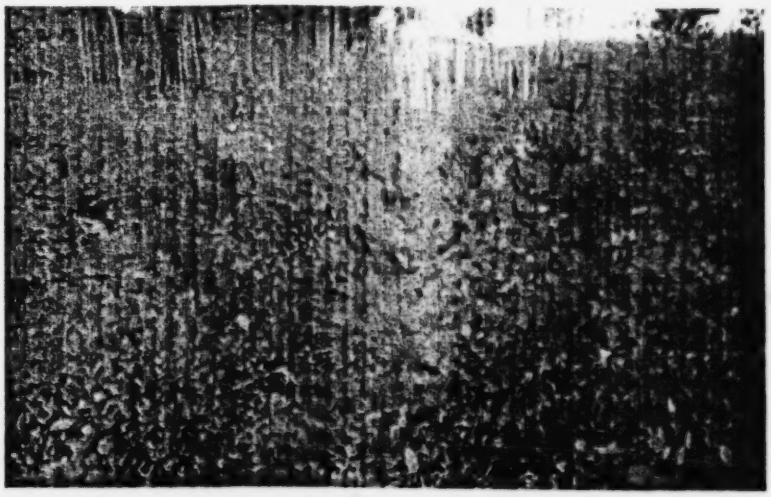

FIGURE 15 *The Aspen Complex prior to brushing in the IDFdk1 variant.*
Photo credit: Jean Mather.

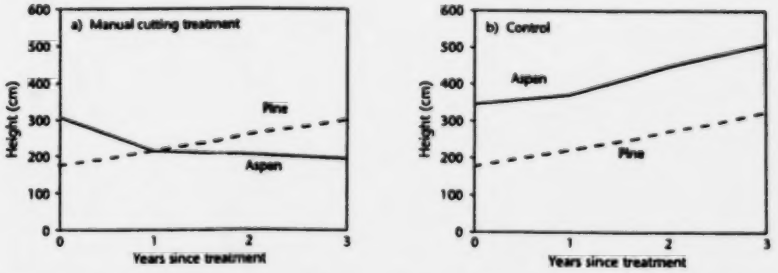

FIGURE 16 *Comparison of average lodgepole pine and aspen height profiles in (a) the manual cutting treatment and (b) the control in the IDF/MS Aspen Complex during the 3-year measurement period.*

ASPEN COMPLEX

The *Aspen* Complex is characterized by relatively pure stands of trembling aspen, sometimes with lesser quantities of paper birch or black cottonwood (Figure 15). Where birch and/or cottonwood are at least as abundant as aspen, the community is known as the *Mixed Broadleaf-Shrub* Complex. Aspen occurs across a broad range of nutrient and moisture regimes in the southern interior, and is most common in the IDF, MS, and ICH zones. It reproduces mainly by suckering from root buds and is encouraged by treatments that remove the forest canopy and expose mineral soil. It is discouraged by site preparation treatments that break up the root system or compact the soil. The complex may reduce light availability to understorey conifers and reduce soil water availability on drier sites. It may also benefit conifers by retaining nutrients within the ecosystem, protecting them from frost or insect damage, reducing the spread of root disease, and increasing resistance to windthrow. Brushing treatments applied to this complex include manual cutting, girdling, foliar glyphosate, cut-and-spray glyphosate, and basal application of triclopyr.

One brushing treatment was examined in the *Aspen* Complex:

- Manual cutting in 7- to 10-year-old lodgepole pine plantations in the IDF/MS zones. Broadleaves were broadcast cut on one site and cut to within 2 m of the drip line on a second site. On the third site, small broadleaves were broadcast cut 1 year and large

stems were girdled the following year. We report 3-year results.

Seedling survival responses (Table 1)
Brushing had no effect on pine survival, which was 100% in both the treatment and the control after 3 years.

Seedling growth responses (Table 1)
- Three years after cutting, diameter increment was 41% greater among treated than control seedlings (0.72 versus 0.51 cm/yr, data not shown), but there were no differences in total diameter, height, or leader length. H:D ratio was smaller among seedlings in the treatment than in the control.
- Cutting successfully reduced average aspen height below that of pine, whereas control pine continued to be overtopped (Figure 16).

Vegetation responses (Tables 2 and 3)
- Manual cutting reduced broadleaf height, but not until year 3, because treatment occurred over a period of 2 years at one of the study sites. None of the other measures of vegetation abundance was significantly reduced because of the variability among sites.
- Ninety-four percent of cut stumps produced an average of four suckers per stump. Three years after cutting, suckers had grown to an average height of 138 cm.
- Manual cutting did not affect the richness or diversity of vascular plant species in the *Aspen* Complex.

Competition thresholds (Table 4)
- Competition was of moderate importance and low intensity in the *Aspen* Complex, which helps explain why conifer growth improved only slightly following brushing.
- Competition thresholds for lodgepole pine were 31% broadleaf cover, 3167 total broadleaf stems/ha, and 43 CRH. Aspen of all sizes were included in all threshold calculations.
- For Douglas-fir, competition thresholds were 20% aspen cover, 2325 total broadleaf stems/ha, and 37 CRH.
- Comparisons are difficult, given differences in measures of aspen competition, but our analysis suggests that our thresholds are comparable to those derived in other studies (e.g., Newsome 1997). Brushing treatments should aim to reduce localized aspen abundance below the identified thresholds.
- Threshold values apply to localized neighbourhoods around individual conifers. Most conifers were already growing below these thresholds on our study sites, and we therefore recommend that brushing treatments be applied only around suppressed conifers that are growing in competitive environments above the thresholds. Consideration should be given, however, to future potential competitive conditions. Broadcast brushing treatments will reduce average vegetation abundance well below the thresholds.

Management implications
- We found that brushing was not required to maintain 100% survival and good vigour of established lodgepole pine growing among moderate (average 26%) cover of aspen on mesic sites in the IDF and MS zones of southern interior British Columbia.
- Minor growth improvements occurred among pine as a result of manual cutting, but further study is required to determine whether these short-term increases will affect stand yield.
- Our study suggests that lodgepole pine growing among the *Aspen* Complex cannot be expected to meet the conifer:vegetation height ratio for free-growing without brushing intervention, even under the new guidelines (British Columbia Ministry of Forests 2000). Manual cutting appears to reduce aspen height sufficiently to meet free-growing requirements.
- Manual cutting of the *Aspen* Complex is unlikely to affect vascular plant species richness or diversity.

MIXED BROADLEAF-SHRUB COMPLEX

The *Mixed Broadleaf-Shrub* Complex is dominated by paper birch, with lesser amounts of trembling aspen and black cottonwood (Figure 17). Where aspen or cottonwood are dominant, the complexes are known as *Aspen* and *Cottonwood-Shrub*, respectively. Willow, Sitka alder, thimbleberry, and fireweed are common in the understorey of the *Mixed Broadleaf-Shrub* Complex. In southern interior British Columbia, this community occurs mainly in ICH, wetter IDF, and some MS and SBS subzones. The complex appears to negatively affect understorey conifers by reducing light availability. However, it may also benefit conifers by reducing incidence of *Armillaria* root disease, providing protection from summer frosts, retaining nutrients on site, and contributing to a healthy soil foodweb. Brushing treatments applied to the *Mixed Broadleaf-Shrub* Complex include manual cutting, foliar glyphosate, cut stump–glyphosate, girdling, and cut-and-spray glyphosate.

Four brushing treatments were examined in the *Mixed Broadleaf-Shrub* Complex, for which we report 5-year results:
- Manual cutting in 5- to 8-year-old Douglas-fir plantations in the ICH/IDF zones. Broadcast cutting treatments were applied once on dates in July to October.

- Manual cutting in 3- to 10-year-old lodgepole pine plantations in the ICH zone. Vegetation was broadcast cut on two sites, and in 1.0 m radii around seedlings on a third site. Treatments were applied once on dates from mid-August to September.
- Cut stump–glyphosate in 8- to 9-year-old Douglas-fir plantations in the ICH zone. Treatments were broadcast applied on two sites, and broadleaf stems >10 cm dbh were retained on a third site. Treatments were applied once on dates from mid-June to mid-October.
- Girdling in 5- to 17-year-old Douglas-fir plantations in the ICH zone. Treatments took place in August and mid-October, and were variable; all broadleaf stems were girdled on one site, those >5 cm dbh were girdled on a second site (smaller stems were cut), and, on the third site, stems were injected with E-Z-JECT glyphosate capsules, which had a similar effect to girdling.

FIGURE 17 *The* Mixed Broadleaf-Shrub *Complex prior to brushing in the ICHmk1 variant.*
Photo credit: Jean Mother.

Seedling survival responses (Table 1)
- Brushing was not needed to ensure good survival of established Douglas-fir (>87%) or lodgepole pine (>90%).
- *Armillaria*-related mortality increased among Douglas-fir following girdling (3% mortality in the control versus 8% in the treatment) and lodgepole pine following manual cutting (2% mortality in the control versus 9% in the treatment).
- Seedling vigour improved as a result of brushing.

Seedling growth responses (Table 1)
- Douglas-fir growth increased as a result of all three brushing treatments, and the largest response occurred in the cut stump–glyphosate treatment. By year 5, diameter had increased by 14% in the manual cutting treatment and 52% in the cut stump–glyphosate treatment. The response to girdling was variable among sites because broadleaves died slowly and not all were treated. The only significant height response among Douglas-fir occurred following cut stump–glyphosate application.
- Lodgepole pine diameter had increased by 37% and H:D ratio had decreased significantly 5 years after manual cutting. Height did not increase following treatment.
- Cut stump–glyphosate reduced average broadleaf height below that of Douglas-fir during the 5-year measurement period (Figure 18a, b), and girdling had a variable effect because not all stems were girdled (Figure 18c, d). Broadleaves that were manually cut outgrew Douglas-fir within 3 years (Figure 18e, f), whereas pine remained above broadleaves following cutting (Figure 19).

Vegetation responses (Tables 2 and 3)
- Cut stump–glyphosate reduced vegetation cover and height to a greater extent than manual cutting or girdling. It was the only treatment that reduced vegetation height below that of Douglas-fir for at least 5 years. Manual cutting reduced vegetation height below that of the faster-growing lodgepole pine during the 5-year measurement period.
- Girdling killed trees slowly and some stems were not girdled. This resulted in highly variable vegetation responses that were not statistically significant, even though reductions in height and cover were quite large. This helps explain why differences in Douglas-fir diameter and H:D ratio were also not significant.
- Eighty to one hundred percent of stumps sprouted following manual cutting, 14% sprouted following girdling, and 25% sprouted following cut stump–glyphosate. Sprouts reached heights of 2–2.75 m within 5 years. Sprouting was more vigorous than expected in the cut stump–glyphosate treatment because many stumps missed being treated at one site.
- None of the treatments affected the richness or diversity of vascular plant species.

Competition thresholds (Table 4)
- Competition was of moderate importance and intensity, which helps explain why conifer growth increased following brushing.
- Broadleaves of all sizes were included in the determination of competition thresholds.
- Competition thresholds for Douglas-fir averaged 3880 broadleaf stems/ha, 27% for broadleaf cover, and 38 for CRH. Thresholds did not vary within the age range of stands studied. However, our sample size of older stands was limited, and

age-related variation should therefore be investigated further across a greater number of sites.

- Competition thresholds for lodgepole pine averaged 4130 total broadleaf stems/ha, 27% for broadleaf cover, and 34 for CRH.
- Competition thresholds for interior spruce averaged 2500 total broadleaf stems/ha, 20% for broadleaf cover, and 27 for CRH.
- Reducing localized broadleaf abundance to below these threshold values should improve conifer diameter growth.
- Threshold values apply to localized neighbourhoods around individual conifers. Most conifers were already growing below these thresholds on our study sites, and we therefore recommend that brushing treatments be applied only around suppressed conifers that are growing in competitive environments above the thresholds. Broadcast brushing treatments will reduce average broadleaf cover and densities well below threshold values.

Management implications

- Brushing was not necessary to ensure good (>87%) survival of established seedlings on our study sites. In some cases, cutting or girdling increased mortality from *Armillaria*, whereas chemical treatments did not. Further research is required on brushing effects on root disease, but, at present, we recommend avoiding brushing in *Armillaria*-infected stands if possible. If brushing these stands cannot be avoided, we recommend brushing suppressed conifers only using chemical treatments.
- Average conifer diameter growth can be improved by brushing the *Mixed Broadleaf-Shrub* Complex. In our study, the largest increases occurred as a result of cut stump–glyphosate treatment.

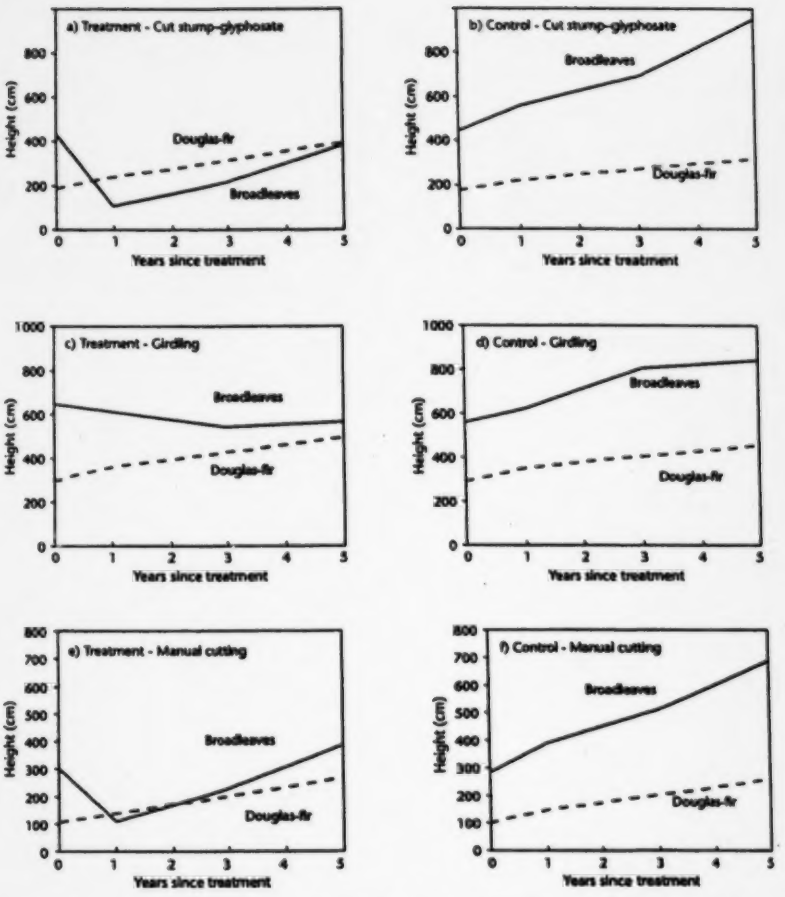

FIGURE 18 *Comparisons of average Douglas-fir and broadleaf height profiles in the treatment and the control following: (a, b) cut stump–glyphosate; (c, d) girdling; and (e, f) manual cutting in the* Mixed Broadleaf-Shrub *Complex during the 5-year measurement period.*

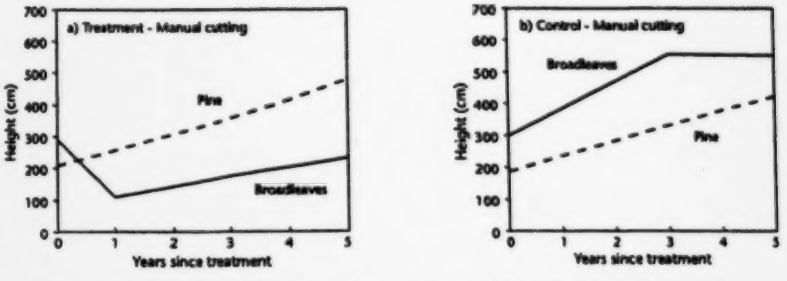

FIGURE 19 *Comparison of average lodgepole pine and broadleaf height profiles in (a) the manual cutting treatment and (b) the control in the ICH* Mixed Broadleaf-Shrub *Complex during the 5-year measurement period.*

- Reducing broadleaf abundance below the competition thresholds identified in this study should improve conifer diameter growth, but further reductions may have unpredictable effects.
- On average, manual cutting allowed lodgepole pine to meet conifer:vegetation height ratio requirements for free-growing, but was not successful for slower-growing Douglas-fir. Cut stump–glyphosate successfully reduced vegetation below the height of most Douglas-fir, and girdling had a variable effect.

Discussion

PROBE is evaluating the effectiveness of operational brushing practices at meeting management objectives for plantation performance, free-growing, and biodiversity on mesic sites in the southern interior of British Columbia. The brushing treatments and plant communities we studied have been common components of operational brushing programs in the Kamloops and Nelson forest regions throughout the 1990s. Our PROBE results show that, in general, competition between brush and conifers is more variable in current plantations (sufficiently restocked sites harvested post-1987) than we had thought, based on earlier experiments. This is partly accounted for by some important design differences between PROBE and many other research experiments. PROBE was designed to provide an accurate picture of the average efficacy of operational treatments under typically variable and moderately competitive conditions, whereas many research experiments commonly investigate "potential" responses and underlying competition mechanisms in highly brushy, more uniform conditions. These differences are discussed fully by Simard et al. (2001).

We found that conifer responses to operational brushing treatments were often variable and smaller than expected. For example, of the 15 brushing scenarios examined, conifer survival was improved only among spruce following manual cutting of the *Ericaceous Shrub* Complex. Possible reasons for the lack of survival response depended on the specific brushing scenario, and included: (a) vegetation competition was, on average, not intense enough to threaten overall survival; (b) the treatment was ineffective at reducing vegetation competition; (c) the treatment was applied too late to reduce mortality; or (d) a factor other than vegetation competition was affecting survival. In the *Mixed Broadleaf-Shrub* Complex, we found examples of reduced survival following brushing because of increased mortality due to *Armillaria* root disease.

Conifer growth improved in some cases, and not in others. Diameter increased following foliar glyphosate application in the *Fern* Complex, following manual cutting in the *Mixed Shrub* Complex, and following manual cutting and cut stump–glyphosate treatments in the *Mixed Broadleaf-Shrub* Complex. In general, the greatest average diameter increases occurred following treatments that caused sustained reductions in vegetation abundance, and in complexes where dense vegetation had overtopped conifers and suppressed their growth. In all other complexes, conifer diameter was unaffected by brushing. In the *Fireweed* Complex, for example, glyphosate application resulted in sustained vegetation reductions, but seedling diameter did not improve, probably because seedlings were experiencing little competition. Similarly, diameter was not affected by single manual cutting treatments in the *Fireweed*, *Ericaceous Shrub*, *Dry Alder*, *Wet Alder*, and *Aspen* complexes, or by single grazing treatments in the *Mixed Shrub* and *Fireweed* complexes, mainly because the treatments did not sufficiently relieve the main growth-limiting factors. Conifer height was generally unaffected by brushing in our study. The only exception was an increase in Douglas-fir height following cut stump–glyphosate treatment in the *Mixed Broadleaf-Shrub* Complex. Many other studies demonstrate that height is less responsive than diameter to interspecific competition. In our study, height:diameter ratio was sometimes significantly reduced following treatment, even when no treatment effects were found in either diameter or height. In our view, height:diameter ratio is a morphology index that should be interpreted in combination with height and diameter responses. Further study is needed to determine whether the short-term survival and growth responses measured in this study will eventually affect stand yield.

Vegetation recovery varied according to the brushing treatment and the complex where it was applied. Most herbs and shrubs recovered within the season that single-pass manual cutting and grazing treatments were applied to the *Fireweed* and *Mixed Shrub* complexes, but were reduced for at least 5 years following foliar glyphosate application to the *Fireweed* and *Fern* complexes. Vegetation recovery was generally slower following a single manual cutting in the tall shrub and broadleaf complexes than in the short shrub and herb complexes. Shrubs are generally expected to recover within 3 years of manual cutting in the *Ericaceous Shrub* and *Dry Alder* complexes, whereas shrubs or broadleaves are projected to generally take longer than 3–5 years to recover their height in the *Wet*

Alder, Mixed Broadleaf-Shrub, or *Aspen* complexes. Both cut stump–glyphosate and girdling had prolonged effects in the *Mixed Broadleaf-Shrub* Complex, where crown cover was only one-quarter that of the control after 5 years, but the reduction was immediate following the chemical treatment and was delayed for 3 years following girdling. None of the brushing treatments had a sustained effect on either vascular plant species richness of diversity, which agrees with other brushing studies in British Columbia (Haeussler et al. 1999; Boateng et al. 2000). However, several berry-producing shrub species tended to decrease following foliar glyphosate treatment in the herb and shrub complexes, and some understorey herb species tended to increase following manual cutting of shrubs or trees in the tall shrub and broadleaf complexes.

Competition thresholds for conifer diameter growth were evident in all of the vegetation complexes studied, but were often diffuse in nature and varied considerably among replicate sites. The thresholds varied among biogeoclimatic zones according to environmental limitations, such that conifers had higher thresholds in milder than in harsher climates within a particular vegetation complex. Thresholds also tended to vary among conifer species along traditional patterns of shade tolerance, such that shade-tolerant conifers generally had higher thresholds than intolerant conifers within a particular vegetation complex and biogeoclimatic zone. The ranges in average cover thresholds by complex were:

- 18–28% for broadleaves in the *Mixed Broadleaf-Shrub* Complex,
- 21–31% for broadleaves in the *Aspen* Complex,
- 33–37% for alder in the *Dry Alder and Wet Alder* complexes,
- 68–78% for shrubs in the *Mixed Shrub* Complex
- 52% for shrubs in the *Ericaceous Shrub* Complex, and
- 35–46% for fireweed in the *Fireweed* Complex.

Broadleaf density thresholds in the *Aspen* Complex averaged 3180 and 2600 total stems/ha for lodgepole pine and Douglas-fir, respectively, and those in the *Mixed Broadleaf-Shrub* complex averaged 2500, 3367, and 3664 total stems/ha for spruce, lodgepole pine, and Douglas-fir, respectively. At the time the thresholds were derived, conifers were generally <13 years old and broadleaves were within 4 years of the age of the conifers. These thresholds included broadleaf trees of all sizes, whether shorter or taller than the target conifers. In a separate study, Simard (2001, submitted) derived two sets of thresholds for diameter growth of 9- to 13-year-old conifers in the ICHmw subzone: one using all-sized paper birch trees and another using only those paper birch trees that were taller than the target conifers. In that study, the density thresholds for western redcedar, Douglas-fir, and western larch were 4500, 4050, and 4000 birch stems/ha where all-sized paper birch were included, of which the Douglas-fir threshold was comparable to that derived in this study. Where only taller birch were included, Simard (2001, submitted) found that the thresholds were 3325, 2575, and 733 birch stems/ha for western redcedar, Douglas-fir, and western larch, respectively.

Our analyses of competition importance, intensity, and thresholds showed that vegetation competition was of low or moderate importance and intensity to conifer diameter growth in all of the complexes studied (Table 4). We found, in general, that the *Fireweed* and *Dry Alder* complexes were comparatively the least competitive plant communities for conifers, whereas the *Fern* and *Mixed Broadleaf-Shrub* were the most competitive. We also found that competition was an important constraint to only a portion of conifers in young plantations. Averaged across all sites, 30% of untreated conifers occurred in competitive environments above the thresholds. Brushing was applied to all trees to relieve competition constraints, as is usually done in operations, but only a portion of treated trees responded. This, together with the patchiness of vegetation, implies that the broadcast approach to brushing, common in the past, may not always be necessary. Instead, selective treatments could focus on competition-stressed trees only, possibly reducing brushing costs and preserving, as much as possible, the plant communities and their roles in succession.

In conclusion, we found that operational brushing was effective at improving conifer performance in some complexes, but was apparently unnecessary or ineffective in others. In some cases, we suspected that other factors were more limiting to conifer performance than vegetation competition. We hope that PROBE results can be used to focus brushing resources towards sites where seedling performance can be significantly improved, and also that it will help with the prescription of effective treatments. We recommend that conifer responses to brushing be quantified over the long term, and that, for some complexes, data be collected across a wider range of site series.

TABLE 1 *Mean conifer seedling survival and growth responses following brushing*[a]

Complex	Treatment	BEC zone	Crop tree species and age[b]	Assessment year	Survival %			Diameter (cm)			Height (cm)			Leader length (cm)			H:D ratio		
					C	T	Sig[c]	C	T	Sig[c]	C	T	Sig[c]	C	T	Sig[c]	C	T	Sig[c]
Fireweed																			
	Manual cutting	ESSF/ ICH	Se 2–4 years	3	97	94	ns	2.28	2.14	ns	96.2	94.0	ns	14.7	16.1	ns	45	45	ns
	Manual cutting	ICH/ ESSF	Pl 1–3 years	5	81	94	ns	3.75	3.86	ns	180.7	181.6	ns	40.0	36.8	ns	52	49	ns
	Glyphosate	ESSF/ ICH	Se 1–5 years	5	88	94	ns	2.06	2.80	ns	95.0	116.0	ns	13.7	20.7	ns	47	42	**
	Grazing	ESSF	Se 0–5 years	1	95	93	ns	1.08	1.08	ns	45.3	47.5	ns	9.7	8.5	ns	47	48	ns
Fern																			
	Glyphosate	ICH	Sx 2–4 years	5	89	97	ns	2.61	4.14	**	130.6	163.8	**	15.2	23.1	**	50	40	**
Mixed Shrub																			
	Manual cutting	ESSF/ ICH	Sx 0–2 years	3	71	79	ns	1.28	1.58	**	74.5	80.9	ns	12.2	14.1	ns	63	55	**
	Grazing	ICH/ ESSF	Sx 1–2 years	1	95	93	ns	0.69	0.76	ns	44.2	42.5	ns	10.4	8.9	ns	62	54	ns
Ericaceous Shrub																			
	Manual cutting	ESSF	Se 0–2 years	5	71	89	**	1.00	1.16	ns	53.1	57.1	ns	5.8	7.1	**	54	50	**

TABLE 1 *Continued*

Complex	Treatment	BEC zone	Crop tree species and age[b]	Assessment year	Survival %			Diameter (cm)			Height (cm)			Leader length (cm)			H:D ratio		
					C	T	Sig[c]	C	T	Sig[c]	C	T	Sig[c]	C	T	Sig[c]	C	T	Sig[c]
Dry Alder																			
	Manual cutting	MS	Pl 5–7 years	5	99	96	ns	6.36	6.58	ns	323.4	317.1	ns	38.1	46.2	ns	51	48	ns
Wet Alder																			
	Manual cutting	ESSF/ ICH	Se 4–6 years	3	99	87	ns	1.88	2.56	ns	103.6	114.1	ns	10.1	11.4	ns	56	46	**
Aspen																			
	Manual cutting	IDF/ MS	Pl 7–10 years	3	100	100	ns	5.15	5.81	ns	322.6	298.6	ns	40.6	37.6	**	66	56	**
Mixed Broadleaf-Shrub																			
	Manual cutting	ICH/ IDF	Fd 5–8 years	5	89 (10%)[d]	87 (12%)	ns (ns)	4.51	5.14	**	257.6	271.9	ns	33.0	42.6	**	58	53	ns
	Manual cutting	ICH	Pl 3–10 years	5	90 (2%)	91 (9%)	ns (ns)	6.14	8.42	**	422.5	476.7	ns	39.2	52.7	ns	69	56	**
	Cut stump–glyphosate	ICH	Fd 8–9 years	5	94 (5%)	96 (4%)	ns (ns)	5.06	7.69	**	318.5	398.4	**	23.0	45.3	**	63	53	**
	Girdling	ICH	Fd 5–17 years	5	97 (3%)	90 (8%)	** (**)	8.68	10.71	ns	451.9	495.8	ns	22.3	34.9	**	61	50	ns

[a] Means are from data collected in the latest assessment year. Full data are presented in Simard et al. (2001).
[b] Age since planting.
[c] "**" indicates control and treatment means are significantly different ($p \leq 0.10$). "ns" indicates means are not significantly different ($p > 0.10$).
[d] Values in brackets are percent mortality due to *Armillaria* root disease.
C = Control T = Treated

TABLE 2 *Mean vegetation cover reponses following brushing*[a]

Vegetation complex	Treatment	BGC zone	Assessment year	Cover of vegetation group or species #1 (%)					Cover of vegetation group or species #2 (%)					Cover of vegetation group or species #3 (%)				
				Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover
Fireweed																		
	Manual cutting	ESSF/ ICH	3	Total veg	74	81	ns	<1	Fireweed	42	46	ns	<1	Shrubs	24	19	(*)[c]	<1
	Manual cutting	ICH/ ESSF	5	Total veg	87	85	ns	<1	Fireweed	32	28	ns	<1	Shrubs	26	27	ns	<1
	Glyphosate	ESSF/ ICH	5	Total veg	89	82	(*)[c]	>1 but <3	Fireweed	46	15	**	>5	Shrubs	40	20	***	>5
	Grazing	ESSF	1	Total veg	92	82	ns	<1	Fireweed	52	35	ns	<1	Herbs	74	66	ns	<1
Fern																		
	Glyphosate	ICH	5	Total veg	88	76	**	>5	Lady fern	37	5	**	>5	Thimbleberry	11	6	ns	>3 but <5
Mixed Shrub																		
	Manual cutting	ICH/ ESSF	3	Total veg	86	87	ns	<1	Shrubs	52	42	ns	>1 but <3	Herbs	57	60	ns	<1
	Grazing	ICH/ ESSF	1	Total veg	93	80	ns	<1	Shrubs	59	67	ns	<1	Fireweed	24	9	**	>1
Ericaceous Shrub																		
	Manual cutting	ESSF	5	Total veg	78	72	ns	>1 but <3	Shrubs	58	50	ns	>1 but <3	Herbs	44	44	ns	<1

TABLE 2 *Continued*

Vegetation complex	Treatment	BGC zone	Assessment year	Cover of vegetation group or species #1 (%)					Cover of vegetation group or species #2 (%)					Cover of vegetation group or species #3 (%)				
				Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover
Dry Alder																		
	Manual cutting	MS	5	Alder	31	20	ns	<1	Shrubs	51	48	ns	>3 but <5	Herbs	31	31	ns	<1
Wet Alder																		
	Manual cutting	ESSF	3	Total veg	80	79	ns	>1 but <3	Alder	45	17	**	>3	Herbs	37	43	ns	1
Aspen																		
	Manual cutting	IDF/ MS	3	Broadleaves	28	25	ns	<1	Shrubs	32	25	ns	<1	Herbs	38	62	ns	1 but < 3
Mixed Broadleaf-Shrub																		
	Manual cutting	ICH/ IDF	5	Total veg	87	85	(*)[c]	<1	Broadleaves	33	27	(*)[c]	<1	Shrubs	46	45	ns	<1
	Manual cutting	ICH	5	Total veg	95	89	ns	<1	Broadleaves	39	21	ns	<1	Shrubs	47	47	ns	<1
	Cut stump–glyphosate	ICH	5	Total veg	91	78	ns	>3 but <5	Broadleaves	70	15	**	>5	Shrubs	59	48	ns	>1 but <3
	Girdling	ICH	5	Total veg	92	88	ns	>1 but <3	Broadleaves	35	10	ns	>1 but <3	Shrubs	No data			

[a] Means are from data collected in the latest assessment year. Full data are presented in Simard et al. (2001).
[b] "**" indicates control and treatment means are significantly different ($p \leq 0.10$). "ns" indicates means are not significantly different ($p > 0.10$).
[c] "(*)" indicates a statistical difference was found in the latest assessment year, but was interpreted as not being a treatment effect. A full discussion of the results is available in Simard et al. (2001).
C = Control T = Treated

TABLE 3 *Mean vegetation height reponses following brushing*[a]

Vegetation complex	Treatment	BGC zone	Assessment year	Height of vegetation group or species #1 (cm)					Height of vegetation group or species #2 (cm)					Height of vegetation group or species #3 (cm)				
				Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover
Fireweed																		
	Manual cutting	ESSF/ ICH	3	Total veg	98	95	ns	<1	Fireweed	101	105	ns	<1	Shrubs	73	67	ns	<1
	Manual cutting	ICH/ ESSF	5	Total veg	87	86	ns	<1	Fireweed	99	86	ns	<1	Shrubs	99	98	ns	<1
	Glyphosate	ESSF/ ICH	5	Total veg	116	81	ns	>1 but <3	Fireweed	115	100	**	>5	Shrubs	102	66	**	>5
	Grazing	ESSF	1	Total veg	106	75	ns	<1	Fireweed	116	74	ns	<1	Herbs	103	54	**	>1
Fern																		
	Glyphosate	ICH	5	Total veg	104	79	**	>5	Lady fern	80	37	**	>5	Thimbleberry	57	31	**	>5
Mixed Shrub																		
	Manual cutting	ESSF/ ICH	3	Total veg	99	95	ns	>1 but <3	Shrubs	87	88	ns	<1	Herbs	99	91	ns	<1
	Grazing	ICH/ ESSF	1	Total veg	97	74	ns	<1	Shrubs	96	91	ns	<1	Fireweed	117	94	**	>1
Ericaceous Shrub																		
	Manual cutting	ESSF	5	Total veg	104	87	ns	>1 but <3	Shrubs	115	98	ns	>1 but <3	Herbs	35	31	ns	<1

TABLE 3 *Continued*

Vegetation complex	Treatment	BGC zone	Assessment year	Height of vegetation group or species #1 (cm)					Height of vegetation group or species #2 (cm)					Height of vegetation group or species #3 (cm)				
				Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover	Group or species	C	T	Sig[b]	Years to recover
Dry Alder																		
	Manual cutting	MS	5	Alder	255	165	ns	>1 but <3	Shrubs	228	143	ns	<1	Herbs	60	66	ns	<1
Wet Alder																		
	Manual cutting	ESSF/ ICH	3	Total veg	245	134	**	>3	Alder	267	146	**	>3	Herbs	65	81	ns	<1
Aspen																		
	Manual cutting	IDF/ MS	3	Broadleaves	367	166	**	>3	Shrubs	143	108	ns	<1	Herbs	37	32	ns	<1
Mixed Broadleaf-Shrub																		
	Manual cutting	ICH/ IDF	5	Total veg	593	318	**	>5	Broadleaves	688	386	**	>5	Shrubs	146	102	ns	<1
	Manual cutting	ICH	5	Total veg	504	329	ns	<1	Broadleaves	550	230	**	>5	Shrubs	156	114	ns	>3 but <5
	Cut stump–glyphosate	ICH	5	Total veg	934	194	**	>5	Broadleaves	952	385	**	>5	Shrubs	118	112	ns	>3 but <5
	Girdling	ICH	5	Total veg	737	457	ns	>3 but <5	Broadleaves	844	569	ns	<1	Shrubs	No data			

[a] Means are from data collected in the latest assessment year. Full data are presented in Simard et al. (2001).
[b] "**" indicates control and treatment means are significantly different ($p \leq 0.10$). "ns" indicates means are not significantly different ($p > 0.10$).
C = Control T = Treated

TABLE 4 *Summary of competition thresholds, importance, and intensity by vegetation complex, biogeoclimatic zone, and conifer species*

Vegetation complex	BGC zone	Conifer species	Conifer age[a] (years)	Vegetation component used as a measure of competition[b]	Cover threshold[c] (%)	CRH threshold[d]	Density threshold[e] (stems/ha)	Competition importance[f]	Competition intensity[g]
Fireweed									
	ICH	Se	0–4	Fireweed	46	60	-	Low	Low
	ESSF	Se	0–5	Fireweed	35	46	-	Low	Low
	ICH	Pl	0–5	Fireweed	40	49	-	Low	Low
Fern									
	ICH	Sx	1–4	Herbs	None	58	-	Moderate	Moderate
Mixed Shrub									
	ICH	Sx	0–2	Shrubs	76	84	-	Moderate	Low
	ICH	Cw	0–1	Shrubs	68	187	-	Moderate	Low
	ICH	Fd	2–3	Shrubs	78	48	-	Moderate	Low
Ericaceous Shrub									
	ESSF	Se	0–9	Shrubs	52	73		Moderate	Low
Subalpine Herb									
	ESSF	Se	0	Herbs	None	184	-	Low	Low
Dry Alder									
	MS	Pl	5–11	Alder	33	38	-	Low	Low
Wet Alder									
	ICH/ ESSF	Se	5–10	Alder	37	107	-	Low	Moderate
Aspen									
	IDF/ MS	Pl	2–10	Aspen	31	31	3180	Moderate	Low
	ICH	Fd	2–10	Aspen	21	19	2400	Moderate	Low
Mixed Broadleaf-Shrub									
	ICH	Fd	2–19	Broadleaves	28	39	3664	Moderate	Moderate
	ICH	Pl	3–11	Broadleaves	18	15	3367	Moderate	Moderate
	ICH	Sx	1–13	Broadleaves	20	27	2500	Moderate	Moderate

[a] Age of conifers used in the threshold determinations.
[b] Vegetation component used in determinations of cover, CRH, and density thresholds (notes c, d, e).
[c] Threshold for conifer diameter determined using cover of the chosen vegetation component.
[d] Threshold for conifer diameter determined using CRH, which was calculated as: CRH = ("vegetation component" cover * "vegetation component" modal height)/conifer height.
[e] Threshold for conifer diameter determined using the total density of broadleaf stems.
[f] Competition importance evaluated based on the adjusted r^2 values of simple linear regressions relating conifer diameter (Y) to competition index (X = cover, density or CRH), where the model was $Y = \beta_0 + \beta_1 X$. Low importance: adjusted $r^2 < 0.25$; moderate importance: adjusted r^2 0.25–0.60; high importance: adjusted $r^2 > 0.60$.
[g] Competition intensity evaluated based on the slope of simple linear regressions relating conifer diameter (Y) to competition index (X = cover, density or CRH), where the model was $Y = \beta_0 + \beta_1 X$. Low intensity: $\beta_1 < -0.030$; moderate intensity: β_1 -0.030 to -0.070; high intensity: $\beta_1 > -0.070$.

Acknowledgements

We gratefully acknowledge the licensees and forest districts in the Kamloops and Nelson forest regions for their contributions and support of the PROBE program. Special thanks to Skyline Forestry Consultants Ltd., Newhouse Woodland Consultants, Silver Ring Forestry Ltd., J. Heineman Forestry Consulting, JMJ Holdings Inc., Pacific Regeneration Technologies Inc., and Silvasmart Forestry Services for establishment, monitoring, and maintenance of the PROBE sites. Thanks also to Phil Burton, George Harper, Paul Rehsler, Lana Kendall, Bruce Fraser, Jim Wright, and Barbara Zimonick for reviewing this Extension Note. We are grateful to the following agencies for funding assistance: Kamloops and Nelson forest regions and districts, Forest Resource Development Agreement II, Forest Renewal Program, Forest Renewal BC, and Forest Renewal BC Interfor and Merritt Innovative Forest Practices Agreements. Funding assistance by Forest Renewal BC does not imply endorsement of any statements or information contained in this report.

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